

Particle Beam System Having a Mirror Corrector

Related Application

This is a continuation patent application of international  
5 patent application PCT/EP 02/01553, filed February 14, 2002, and  
claiming priority from German patent application 101 07 910.9,  
filed February 20, 2001.

Background of the Invention

The invention relates to a particle beam system having a  
10 mirror corrector. A system of this kind is, for example,  
disclosed in United States Patent 5,319,207. The mirror  
corrector functions in such systems to correct the geometric and  
energy-dependent aberrations of the particle-optical components  
contained in the system.

15 Mirror correctors include a magnetic beam deflector in  
addition to an electrostatic mirror. Such a beam deflector  
functions, to a certain extent, as a switch for the particle  
beams in order to, on the one hand, deflect the particle beam  
exiting from a source to the electrostatic mirror and to deflect  
20 the particle beam, which is reflected at the electrostatic  
mirror, to the downstream imaging optics.

So that the beam deflector, being a  
non-rotational-symmetrical electron-optical component does not  
itself generate aberrations of the second order, it is known from  
25 United States Patent 5,319,207 to symmetrically configure  
corresponding beam deflectors so that the beam deflector has two  
symmetry planes which are perpendicular to the beam paths of the  
particle beams and simultaneously lie in the bisecting line of  
the deflections achieved in the individual regions of the  
30 deflector. Within the beam deflector, a course of the

fundamental paths of the particle beam symmetrical to the symmetry planes is achieved because of the above symmetry in the configuration of the beam deflector and the simultaneous imaging of the symmetry planes onto each other via a mirror or a  
5 combination of a mirror and a field lens. In this way, the aberrations of the second order vanish within the beam deflector. So that this symmetrical course of the beam paths within the deflector is ensured, it is, however, necessary that the electrostatic mirror, on the one hand, is mounted conjugated to  
10 the symmetry planes of the deflector and, on the other hand, simultaneously images the symmetry planes onto each other at an imaging scale of 1:1.

If in this deflector of only two quadratic sector magnets an intermediate imaging plane is imaged into the symmetry planes,  
15 then there results a simple and short configuration but combination aberrations result because of the large dispersion in the mirror and these combination aberrations can be corrected only to a limited extent. If, in contrast, the diffraction plane of the objective lens is imaged into the symmetry plane of the deflector, then such combination aberrations do not occur because  
20 of a vanishing dispersion in the mirror. However, in this operating mode, a dispersion in the image occurs which must be compensated after a two-time passthrough through the deflector. The large focal length of the deflector then, however, requires a reduction of the beam diameter which is realizable only with very  
25 long lengths or at least two-stage objective lens systems and likewise at least two-stage mirror systems.

In United States Patent 5,319,207, deflectors are already described which are dispersion-free for a single passthrough of  
30 the particle beam. These deflectors, however, include either

three different magnetic fields having an additional superposed electrostatic field or magnetic sectors having partially concave outer surfaces. The concave outer surfaces of the magnetic sectors, however, require a corresponding concave formation of  
5 the magnetic coils whereby, in turn, also manufacturing problems occur, especially in a series production.

Summary of the Invention

It is an object of the invention to provide a particle beam system having a mirror corrector which makes possible a generally  
10 simplified and more compact configuration.

The particle beam system of the invention includes: a particle source for emitting particles along a beam path; an objective lens defining a diffraction plane and being mounted on the beam path downstream of the particle source; a mirror corrector unit including an electrostatic mirror disposed on the beam path between the particle source and the objective lens; the mirror corrector further including a magnetic beam deflector disposed on the beam path so as to be disposed between the particle source and the electrostatic mirror and between the electrostatic mirror and the objective lens; and, the magnetic beam deflector being free of dispersion for each single  
15 passthrough of the particles and the magnetic beam deflector including a plurality of quadrupoles which are so determined that on the entire course of the beam path between a first-time exit from the magnetic beam deflector and the objective lens, a maximum of two planes occur conjugated to the diffraction plane  
20 of the objective lens.  
25

As the system described in the above-mentioned United States Patent 5,319,207, the system of the invention also includes a beam deflector which is dispersion free for each single  
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passthrough. Under dispersion-free, it is understood that the dispersion of the deflector is so slight that a vanishing dispersion is achievable with an optimal adjustment of the components of the deflector.

5 In addition to the freedom from dispersion, the deflector has quadrupoles or quadrupole components which are so selected that maximally two planes, which are conjugated to the diffraction plane of the objective lens, are on the entire path course between the first-time exit from the deflector and the  
10 objective lens and, in this way, two intermediate planes of the diffraction plane of the objective lens occur.

Because the deflector is sufficiently telescopic, particle beams, which originate from the intersect point of the symmetry planes with the optical axis, are parallel outside of the  
15 deflector or are only slightly convergent.

A plane, which is conjugated to the diffraction plane of the objective lens, is preferably coincident with the plane of the electrostatic mirror, that is, that plane in which, for all paths, the reversal points lie because of the electrostatic  
20 counterfield. This condition can be adjusted via an additional field lens.

As with known beam deflectors, the beam deflector in the invention also preferably has a first symmetry plane in a first region and a second symmetry plane in a second region so that the  
25 deflection takes place symmetrically to these symmetry planes in each case.

In each of the two regions which are symmetrical to each other, the beam deflector of the invention has at least two outer magnetic sectors, respectively, and at least one inner magnetic sector. Preferably, drift distances in the magnetic-field free  
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intermediate spaces are provided between the outer and inner magnetic sectors.

Since drift distances are provided between the magnetic sectors, the inlet and outlet edges can have a deviating 5 inclination relative to the optical axis whereby a focusing parallel to the direction of the magnetic fields takes place. This focusing by the quadrupole components at the inlet and outlet edges corresponds to the focusing perpendicular to the magnetic field direction caused by the magnetic deflection fields 10 so that the deflector in total generates a stigmatic imaging in the manner of a round lens. The magnetic field direction is generated by the deflecting magnetic fields. Alternatively, or in addition to the inclined inlet and outlet edges, quadrupole elements can, however, also be provided in the deflector or 15 directly ahead or directly rearward of the deflector.

The deflecting angles in the individual magnetic sectors are so selected that after each single passthrough through the deflector, a vanishing total dispersion occurs. Combination aberrations, which occur because of the interaction of the 20 dispersion with the color or aperture aberrations of an electrostatic mirror downstream of the deflector, can thereby be avoided. Furthermore, a dispersion does not occur in the intermediate images which dispersion would have to be extremely precisely compensated in a second passthrough through the 25 deflector. A beam deflector, which is dispersion-free for a single passthrough, can be achieved when the magnetic field in the mid magnetic sector is antiparallel to the magnetic field direction in the external magnetic sectors.

In an advantageous embodiment, the magnetic fields are equal 30 in magnitude in the inner and the two outer magnetic sectors. In

this way, primary coils having the same number of turns can be used for the generation of the different magnetic fields in series connection whereby, in turn, reduced requirements result on the stability of the current sources.

5           The beam deflector is furthermore purely magnetic, that is, neither for deflection of the particle beam nor for focusing perpendicular to the deflection direction are there electrostatic fields provided.

10          The inclination of the inlet and outlet edges of the outer magnetic sectors to the optical axis and the beam deflection because of the magnetic fields in the magnetic sectors are advantageously so selected that particles, which enter parallel to the optical axis, are focused in or in direct proximity of the symmetry plane of the deflector. In this way, it is achieved  
15          that the field paths outside of the deflector run parallel or almost parallel to the optical axis and, as a consequence thereof, the intercept points of the field paths with the optical axis lie far away from the inlet and outlet edges of the deflector. In this way, only a single additional field lens for  
20          imaging the field paths is required but without additional imaging of the axial paths which would require a further intermediate imaging.

25          A corresponding field lens is preferably configured as an electrostatic immersion lens having a center electrode so that, in total, an imaging results. In this way, the beam deflector can be driven even at variable column potential with a fixed potential. Also, other forms of magnetic and/or electrostatic lenses are, however, possible.

30          Furthermore, it is advantageous when one or two octupole elements or elements of higher order are provided between the

beam deflector and the objective lens. Elements of higher order (higher than eight-pole elements) are especially twelve pole elements at least with quadrupole windings, hexapole windings and octupole windings. The twelve pole element(s) can also have 5 dipole windings. Alternative to these dipole windings, two or three separate individual deflection systems are, however, also possible. The twelve pole element(s) can then function as improved stigmators and ensure an overall stigmatic imaging. The twelve pole element(s) can be configured as air coils. It is 10 also conceivable to mount the two twelve pole elements without further deflection systems between the deflector and the objective lens. In this case, however, all twelve poles of both twelve pole elements should be able to be driven separately and independently of each other; that is, all twelve poles can be 15 charged with current. Alternatively, it is conceivable to provide individual deflecting systems between the beam deflector and the first twelve pole element, which follows the beam deflector, and between both twelve pole elements and behind the second twelve pole element seen in the beam direction. The 20 individual beam deflection systems function then for beam adjustment.

Two electrostatic individual deflectors should be mounted between the deflector and the electrostatic mirror. Alternatively, the multipole elements in electrostatic-magnetic 25 configuration can be mounted also between the deflector and the electrostatic mirror, especially, when the structural space provided between the objective lens and the beam deflector is insufficient.

Furthermore, it is advantageous to provide a stigmator 30 between the particle source and the deflector in order to adjust

the imaging conditions by varying the stigmator. These imaging conditions are especially the residual distortion and residual astigmatism in the deflection region of the deflector between the particle source and the electrostatic mirror.

5 It has been shown to be advantageous when the particles between the beam deflector and the electrostatic mirror have an energy which is not below a minimum energy. For this reason, and especially for applications with low kinetic energy of the particles, it is advantageous to provide an electrostatic immersion lens between the particle source and the deflector and to provide an immersion lens between the deflector and the objective lens. With the immersion lens, the kinetic energy of the particles in advance of the entry into the deflector is increased and is again reduced after exiting from the deflector.  
10 In this way, the deflector can be driven at constant kinetic energy of the electrons in the region of the deflector and therefore at constant magnetic deflecting fields.  
15

The total deflection for a single passthrough through the deflector preferably amounts to  $90^\circ$  so that after a two-time  
20 passthrough through the deflector with an intermediate-lying reflection of the particles, the exiting optical axis runs coaxially to the entering optical axis.

The total system with the mirror corrector is preferably so operated that, simultaneously, the chromatic and aperture  
25 aberrations of the total imaging system are corrected between the particle source and the objective lens whereby the resolution of the corresponding component beam system can be increased.

#### Brief Description of the Drawings

The invention will now be described with reference to the  
30 drawings wherein:

FIG. 1 shows a schematic of a raster electron microscope having a mirror corrector in accordance with the invention;

FIG. 2 shows an enlarged view of the beam deflector in FIG. 1; and,

5 FIG. 3 is a diagram showing the courses of the fundamental beam paths for 15 keV electrons through the beam deflector of FIG. 2.

Description of the Preferred Embodiments of the Invention

The raster electron microscope shown in FIG. 1 includes a  
10 particle source 1 having a beam accelerator 2 downstream of the  
particle source 1. After a run-through through the beam  
accelerator 2, the particles are accelerated to the potential of  
the beam-guiding tube 6. A magnetic condenser lens 3 and a  
stigmator 4 following the condenser lens 3 are provided in the  
15 region of the beam-guiding tube 6 which, for example, lies at a  
potential of 10 kV relative to the particle source 1. The  
condenser lens 3 functions to expand the beam in the beam tube  
following below. A first electrostatic immersion lens 5 follows  
the stigmator 4 via which immersion lens the electrons are  
20 further accelerated to a higher kinetic energy, namely, the  
kinetic energy of the inner beam-guide tube 7. In the region of  
the inner beam-guide tube 7, approximately at the center of the  
raster electron microscope, the beam deflector is mounted with  
the magnetic sectors 21 to 25. The beam deflector operates as a  
25 particle-optical beam splitter which deflects the electron beam,  
which enters along a first optical axis OA1, in the direction of  
an optical axis OA2 which is deflected relative to the entering  
optical axis OA1. At the same time, the beam deflector deflects  
an electron beam, which enters in the direction of the deflected  
30 optical axis OA2 in the direction of an exiting-end optical

axis OA3 which runs coaxially to the entry-end optical axis OA1. The beam deflection between the entry-end optical axis OA1 and the deflected optical axis OA2 within the beam deflector takes place symmetrically to a first symmetry plane 26 and the beam  
5 deflection between the deflected optical axis OA2 and the exit-end optical axis OA3 is symmetrical to a second symmetry plane 27. The three magnetic sectors (21, 22, 23), which are run through with the deflection of the entry optical axis OA1 to the deflected optical axis OA2, therefore form a first deflection region which is symmetrical to the first symmetry plane 26. The three magnetic sectors (23, 24, 25), which are run through with the deflection from the deflected optical beam axis OA2 to the exit-end optical axis OA3, form a second deflecting region which is symmetrical to the second symmetry plane 27. The magnetic  
10 field directions in the three outer deflecting magnetic sectors (21, 23, 25) are identical for reasons of symmetry and parallel to each other. In contrast, in the two center magnetic sectors (22, 24), the magnetic field direction is anti-parallel to the magnetic field direction in the three outer magnetic  
15 sectors (21, 23, 25) so that the beam deflection is composed of component deflections in alternating directions. Further details in connection with the beam deflector are described hereinafter with respect to FIG. 2.

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An electrostatic mirror 9 follows the beam deflector in the arm deflected relative to the entering optical axis OA1. The electrons, which are reflected back by the mirror 9, again enter into the magnetic sector 23 but are there deflected in the opposite direction because of the opposite direction of movement relative to the first passthrough through the magnetic sector 23.  
25 Thereafter, the back reflected electrons run through the two

downstream magnetic sectors (24, 25) and thereafter exit along  
the optical axis OA3 coaxially to the entry optical axis OA1 out  
of the beam deflector. The beam deflection is generated by the  
beam deflector in a single passthrough and is designed for 90° so  
5 that the beam deflector overall is symmetrical to the deflected  
optical axis OA2. In addition to their beam deflecting  
characteristics, the magnetic sectors also have imaging  
characteristics and, for this reason, images of the mirror  
plane 29 occur in planes (30, 31) which lie in the proximity of  
10 the symmetry planes (26, 27) of the beam deflector. For ideal  
adjustment, the images of the image plane 29 lie exactly in the  
symmetry planes (26, 27) of the beam deflector, slight deviations  
from these ideal adjustments are, however, not very  
disadvantageous.

15 A second electrostatic immersion lens 15 follows the beam  
deflector directly in the direction of movement of the electrons.  
The electrons are braked by the electrostatic immersion lens 15  
to the energy of the beam-guiding tube 17 in the objective  
lens 16. At the same time, the immersion lens 15 images the  
20 image plane 30 of the mirror plane 29 into a plane in the  
proximity of the diffraction plane 28 of the objective lens.  
Thereafter, a system of two twelve pole elements (11, 13) follows  
in beam direction. The two twelve pole elements (11, 13) each  
have an upstream simple deflection system 10, an intermediate  
25 simple deflection system 12 and a downstream simple deflection  
system 14.

Because of the short focal length and the close spatial  
proximity resulting therefrom between the primary plane and the  
diffraction plane of the objective lens 16, it is relatively  
30 uncritical whether the plane into which the mirror plane 29 is

imaged corresponds exactly with the diffraction plane 28 of the objective lens 16. In total, only two intermediate images of the diffraction plane 28 of the objective lens 16 occur between the mirror plane and the objective lens of which one lies in the 5 vicinity of the intermediate image 30 of the mirror plane 29 and the second lies in the vicinity of the mirror plane 29.

In the normal case, the potential of the beam-guiding tube in the objective lens 16 corresponds to the potential of the beam-guiding tube 6 in the region of the condenser lens 3. The 10 incident electron beam is focused by the objective lens 16 in the focal plane 18 of the objective lens 16. The objective lens 16 can either be configured as a purely magnetic objective lens or as a combination of a magnetic objective lens and an electrostatic immersion lens. In the last case, the 15 electrostatic immersion lens is configured in that the beam-guiding tube 17 ends within the objective lens 16 at the elevation of the pole shoe gap of the objective lens 16 or ends therebehind and the electrons, after exiting from the beam-guiding tube 17, are decelerated to the potential of the 20 specimen mounted in the proximity of the focal plane 18 of the objective lens 16.

The back-scattered or secondary electrons arise because of the interaction with the specimen mounted in the proximity of the focal plane of the objective lens. These back-scattered or 25 secondary electrons are again back accelerated into the beam-guiding tube 17 by the higher potential of the beam-guide tube and pass through the beam path between the objective lens 16 and the beam deflector in the opposite direction. Because of the inverted direction of movement, the back-scattered electrons and 30 secondary electrons are deflected when entering into the beam

deflector in the magnetic sector 25 in the opposite direction so that they are separated from the entering electron beam. With a detector 20 following the beam deflector in the deflected side arm, the secondary electrons as well as the back-scattered 5 electrons can be detected. With an electrostatic lens 19 mounted upstream of the detector 20, an energy separation between back-scattered electrons and secondary electrons is possible in accordance with the counterfield method by applying different potentials.

10           The total beam deflector comprises a total of five magnetic sectors (21 to 25). All five magnetic sectors (21 to 25) include purely convex outer surfaces so that the coils can be produced relatively simply. These coils are required for the generation of the magnetic fields in the magnetic sectors. The two inner 15 magnetic sectors (22, 24) have an identical configuration. Likewise, the three outer magnetic sectors (21, 23, 25) can be identically configured; however, it is also sufficient for the first magnetic sector 21 when this sector (as shown in FIG. 2) has only a configuration symmetrical to one half of the third 20 magnetic sector 23. Likewise, the last outer magnetic sector 25 need only have a symmetrical configuration to one half of the magnetic sector 23 and can be optimized in the other half for the downstream detection system as may be required. The individual 25 magnetic sectors are so configured that the inlet edge 21a of the first magnetic sector 21 is perpendicular to the entry optical axis OA1. The inlet and outlet edges 23c of the third magnetic sector 23 are perpendicular to the deflected optical axis OA2 and the inlet and outlet edges 25b of the magnetic sector 25 are perpendicular to the exiting optical axis OA3. The inclination 30 of the input and output edges determines the focusing effect when

entering and exiting the magnetic deflection fields  $B$  parallel or anti-parallel to the magnetic field direction and therefore perpendicular to the plane of the drawing of FIG. 2.

The inlet and outlet edges (21b, 22a, 22b, 23a, 23b, 5 24a, 24b, 25a) in the interior of the deflector are, in contrast, greatly inclined in each case to the deflected local optical axis. In this way, a focusing parallel or anti-parallel to the magnetic field direction in the magnetic sectors is achieved within the beam deflector so that this focusing by the quadrupole 10 components is just as great as the focusing which is generated perpendicularly to the magnetic field direction by the magnetic fields so that the beam deflector generates a stigmatic image for a single passthrough. This image corresponds to the image of a round lens.

15 The drift path lengths between the individual magnetic sectors and the deflection angles in the individual magnetic sectors result from the situation that freedom of dispersion for a single passthrough is required for the beam deflector and a telescopically incident electron beam should leave the deflector 20 focused as weak as possible. Only one value is available as a free parameter from the magnetic sectors because of the symmetry conditions.

In FIG. 3, the fundamental paths for a single passthrough through the beam deflector in FIG. 2 are shown for an electron 25 having a kinetic energy of 15 keV. As shown, all fundamental paths within the deflector run symmetrically to the symmetry planes (26, 27). The field paths ( $xy$ ,  $y\delta$ ) incident almost parallel to the optical axis OA are focused stigmatically in the symmetry planes (26, 27). Accordingly, a stigmatic diffraction 30 image occurs in the symmetry plane. The focusing of the  $xy$ -path

takes place via the dipole fields in the magnetic sectors; whereas, the focusing of the  $y\delta$ -path takes place via the quadrupole fields which occur in the interior of the beam deflector because of the inclination of the inlet and outlet edges of the magnetic sectors. Since simultaneously the aperture paths ( $x\alpha$ ,  $y\beta$ ) also have a course which is symmetrical to the symmetry plane (26, 27), the total beam deflector operates as a magnetic round lens for a single passthrough. As shown by the course of the dispersion path  $x\kappa$ , the dispersion at the beam deflector vanishes already with a single passthrough so that the beam deflector is dispersion free for a single passthrough.

In FIG. 3, the course of the magnetic field intensity along the optical axis is shown by the curve  $\psi_1$ . The freedom from dispersion of the deflector for a single passthrough results from the requirement that the path integral of the product of the magnetic field intensity  $\psi_1$  and  $x\alpha$  as well as  $xy$  vanishes between the inlet and outlet of the deflector, that is:

$$\int \psi_1 x\alpha dz = 0 \quad \text{and} \quad \int \psi_1 xy dz = 0.$$

In the embodiment shown in FIGS. 1 to 3, only two inner magnetic sectors (22, 25) are provided. It is, however, also possible to split up these inner magnetic sectors into several magnetic sectors so that a deflector having seven or more magnetic sectors and comparable imaging power is provided. Then, for each single passthrough through the deflector 4 correspondingly more magnetic sectors will be passed through.

It is understood that the foregoing description is that of the preferred embodiments of the invention and that various changes and modifications may be made thereto without departing from the spirit and scope of the invention as defined in the appended claims.